Targeting the subsoil to better manage acidity spatially

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Abstract
Subsoil acidity is common in Western Australia (WA). However, historical lime trials have focussed on ameliorating topsoil acidity only. While soil pH is a useful measure of acidity, it has rarely been coupled with potential crop yield to estimate the yield gap (the difference between actual yield and the water limited potential yield). This is required to understand by how much acidity is constraining yields and to target lime application. The relatively low yield increase in the historical lime trials (14%) would likely have been greater if the subsoil was ameliorated and lime use was targeted to severely constrained sites. The yield increases that could occur with full amelioration can be simulated using APSIM by adjusting the ability of roots to grow through acid layers. Increases in yield from lime application are dependent on the soil type, depth of acidity, severity of acidity and seasonal conditions. We use soil maps, yield maps, geophysics and point sampling to diagnose the acidity constraint and extrapolate to areas across the paddock. With this knowledge, lime application could be targeted to increase the lime-use efficiency (kg grain increase per tonne of lime applied). We use a case study paddock from a farm in Bodallin WA to present the methods for diagnosing the subsoil acidity and the gain from targeted lime application. In one paddock the lime-use efficiency was doubled (104 to 200 kg/t) by reducing the limed area from 120ha to target 42ha of the most responsive, below-average yielding area of the paddock.

Keywords
Subsoil acidity, yield gap, root depth, APSIM

Introduction
Subsoil acidity is common in Western Australia (WA) with 45% of the wheatbelt with a pH ($CaCl_2$) less than 4.8 in both the 0.1-0.2m and 0.2-0.3m layers (Gazey et al. 2013). However, historical lime trials in WA have only ameliorated the topsoil. This resulted in the pH increasing by 1 unit in the 0-0.1m layer, with much smaller increases (0.2-0.3 pH units) in the subsoil (Gazey et al. 2014). Average wheat yield increase after was lime applied at least one year previously, was 14% (Gazey et al. 2014). The low yield increases from liming in WA were due to the soil pH not always being a good indicator of the effect on crop yield. This was highlighted by the yield in the unlimed treatments having greater than 75% of yield potential in 40% of the cases in the DAFWA lime trial (Gazey et al. 2014), despite having a pH of <4.8. The yield gap may have provided more insight into determining how severely the acidity was in constraining the yields than just a pH profile.

Greater increases in subsoil pH and crop yield may be possible through higher rates of lime and better incorporation or movement of lime to depth. Farmers have begun trialling higher rates of lime with different methods of incorporation such as grizzly deep digger®, mouldboard plough, rotary spading, slotting and deep ripping. The likely gains from these incorporation methods in terms of soil pH and yield gains are unknown, as there are few trials and these have has insufficient time since the treatments were applied to test the impact on yield. Furthermore, it is difficult to infer the yield gains from these approaches on different soils, acid profiles and rainfall locations. As these amelioration methods are costly, a targeted approach based on likely yield gains may be valuable.

The effect of acidity can be estimated through APSIM modelling (Farre et al. 2010, Wong and Asseng 2007) by restricting root growth in different layers. The lower the pH the more the root growth is reduced. Yield gains from amelioration can then be estimated when the restriction to root growth is reduced or completely removed for different soil types, different acidic soil layers and severity of the acidity in these layers. To target areas for subsoil amelioration on a farm based on the greatest yield gains, we need to; 1) identify the soil types, 2) identify which soils layers are classed as acidic, 3) identify the severity of the acidity and

4) assign a likely yield gain to each area. The severity of the acidity was estimated from the root depth or percentage of potential yield for a known acid profile (inverse model approach). We demonstrate the process on a paddock from the eastern Wheatbelt WA.

The process

The case-study paddock is near Bodallin (31.266 S, 118.942 E) ~ 300km east of Perth WA. The farm has a long term (1913-2012) mean annual rainfall of 311mm with 228mm in the growing season (April-October). The yield monitor data was collected between 2004 and 2009 and the relative yield (RY) calculated for each 25m^2 pixel by dividing the measured yield by the water limited potential yield (Yw) (Oliver and Robertson 2013). Each pixel's performance was classified according to the relative yield: above-average (RY > 0.75), average (0.5<RY< 0.75) and below-average performance (RY<0.5).

1) Identify the soil types

A soil map of the paddock was originally created using Google Earth maps, farmer knowledge and our discussions with the farmer to assign the areas to a DAFWA soil group (Schoknecht 2002) (Fig 1a). The soil map was redefined (Fig 1d) after comparison of geo-located soil samples with the geophysics EM (Fig 1b) and Gamma (Fig 1c) based on Wong et al. (2010) (Table 1). The paddock was originally mapped as predominantly sandy soils classed as deep and shallow acid sands and deep yellow sand. The geophysics and soil sampling separated the sand classes into sand, sandy gravel and acid sandy gravel.

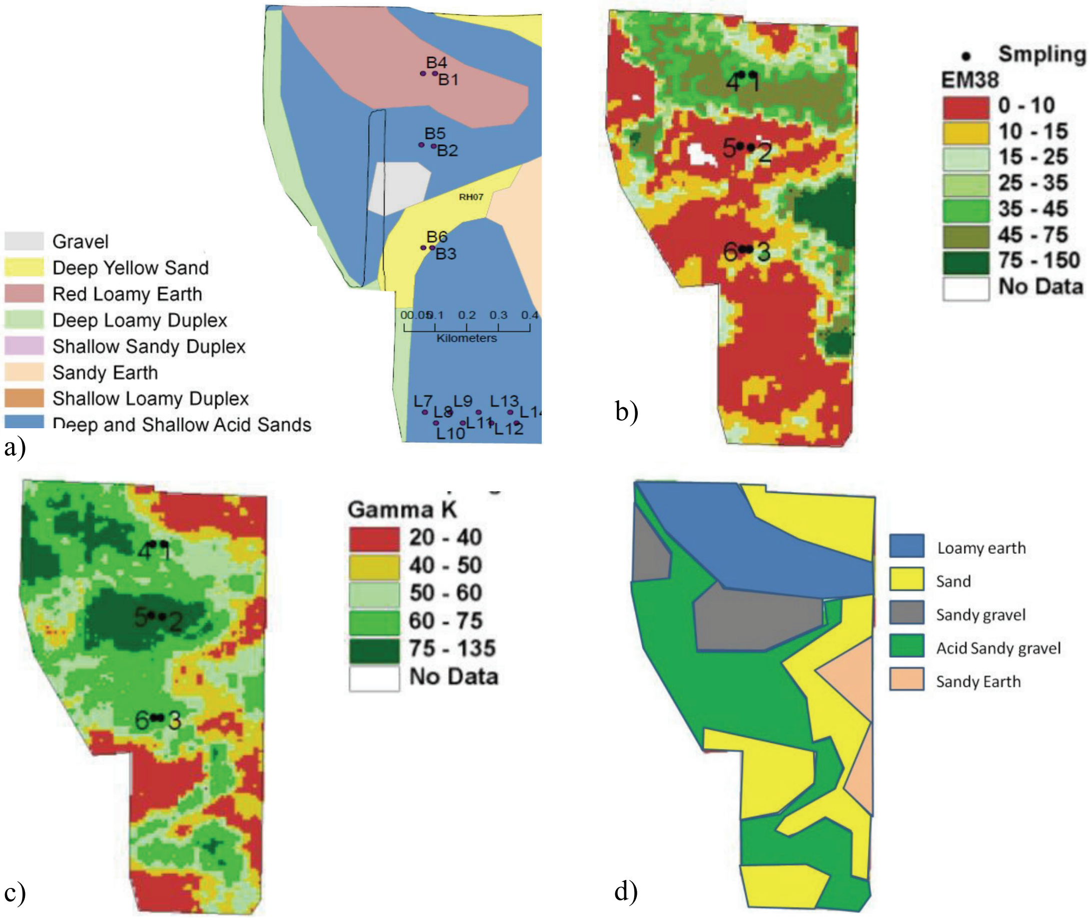

Figure 1. The data layers available for 'Roundhouse' paddock on the Bodallin case study farm a) farmer mud map, b) EM38, c) Gamma K radiometric and d) Soil map redrawn from geophysics. The deep sampling locations were in the different crop performance zones of above-average (B1, B4), average (B2, B5) and below-average (B3, B6).

2 &3) Identify the acidic soil layers and identify the severity of the acidity

Soil tests indicated that the sand, sandy gravel and acid sandy gravel had pH< 4.5 to a depth of 1.8m. The loamy earth was non acidic in all layers while there were no samples of the sandy earth.

We simulated the effects of acidity in APSIM by scaling the potential daily rate of root growth using an exploration factor (xf) for each soil layer. The value of xf ranges between 0 for no root growth to 1 for the maximum rate of root growth. We used a range of xf values (0.1, 0.2, 0.3, 0.5, 0.75 and 1). As acidity occurs in different layers of the soil profile, we varied xf in 0.1m layers of the soil profile between the 0-0.3m layer and 0-1.8m layer. We simulated acidity in the different layers for a sandy soil, sandy loam and a sandy duplex. The low plant available water capacity in the coarse texture sand causes greater percentage gains from amelioration than the sandy loam or duplex soils (Wong et al. 2007). The simulations used rainfall from over 100 years of climate data for the Bodallin weather station (1913-2012) to account for the variable response to amelioration. For example, ameliorating the 0-0.3m layers of a sand which is acidic to 1.8m with an xf =0.2, can, depending on seasonal conditions, change yield by -10% to 100% with a median of 32% yield increase. There were no relationship between yield gains with simple rainfall indices as it was also dependent upon the pattern of rainfall, stored soil water at depth and the requirement of deeper water to meet crop demand.

The severity of the acidity (xf) can be estimated using the relationship with relative yield or root depth (measured or inferred from water remaining in the profile) (Fig 2a,b). These relationships are specific to the soil type, pH profile and the year which the yield or root depth is measured. In this example yield values was taken from yield maps in 2008 and 2009 using both the soil sampling points and an average yield for that soil type (Table 1). The relative yield was calculated using yield potential of 2.20 t/ha in both 2008 and 2009. While root depth was not measured, it would be preferable as it can better differentiate between severities particularly at high xf values (Fig 2a,b).

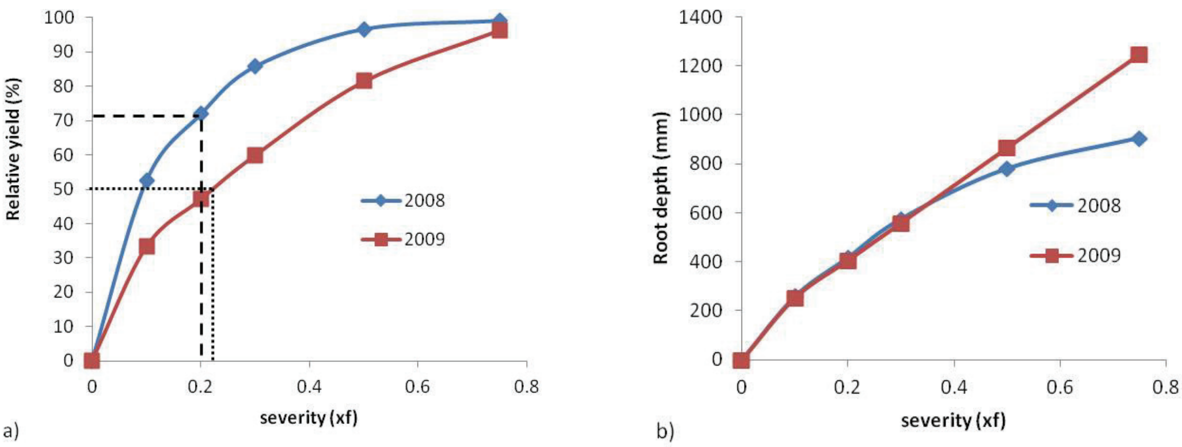

Figure 2. The modelled severity versus a) relative yield curves and b) root depth (mm) for an 0-1.8m acid profile in Bodallin in 2008 and 2009 with the measured relative yield at a point in the gravelly sandy earth of 0.71 in 2008 (---) and 0.51 in 2009 (….) which corresponded to a severity of xf=0.2.

4) Assign a yield gain to each area

Table 1. Soil properties (area, gamma, EMI, pH and Al), the average yield averaged for a soil type for 2008 and 2009, long term crop performance of that area which was used to estimated severity and yield increase for each soil type in a Bodallin paddock.

Soil type	Loamy Earth	Sandy Earth	Sandy gravel	Deep sand	Acid Sandy gravel
Area of paddock (ha)	18ha	6ha	12ha	42ha	42ha
Gamma	high (K>60)	Med (K50-60)	Very high (K>75)	Low (K<20)	high (K>60-75)
EMI	high (EMI>35)	High (EMI >75)	Low (EMI <10)	Low (EMI <10)	Low (EMI <10)
pH (CaCl2)	Neutral 7-8	No measurements	pH<4.5 in surface and 4.2 at depth	pH<4.5 in surface and 4.4 at depth	pH<4.5 in surface and 4.1 at depth
Al (CaCl2)	Not measured		Al >10ppm	Al <3ppm	Al 10-40ppm
Crop performance	Above-average	Above-Average	Average	Average	Below-average
Severity and modelled soil type	none	No measurements	0-1.8 xf =0.2 Sandy loam	0-1.8 xf=0.2 Sand	0-1.8m xf= 0.1 Sand
Average estimated yield increase	0%	0%	15%	32%	74%
Yield (t/ha)	2.4	2.05	1.6	1.58	1.1
Yield after amelioration	2.4	2.05	1.84	2.08	1.91

For each soil type (Fig 1d) a modeled soil type, pH profile and severity was assigned. The yield in each soil type was averaged over 2008 and 2009 using the yield maps. The average yield increase was estimated assuming the top 0-0.3m of the profile was ameliorated (Table 1) and the subsoil (0.3-1.8m) was still acidic.

Targeted lime application

We estimate the yield increase per tonne of lime applied (LUE) if different soil types were targeted for subsoil amelioration. In this analysis we assumed 4 t/ha of lime was applied, the yield was from the average of each soil in 2008 and 2009 and estimated yield increases from Table 1. We then reduced the area which lime was applied based on targeting the sandy soils, average and below average yielding sandy soils, then only those which have high yield increases (Table 2). By targeting only the acid sandy soil, the area for subsoil amelioration was only 34 ha, which double the LUE. This analysis does not take into account gains for ameliorating the topsoil nor the presence of other constraints once the acidity constraint is removed.

Table 2. Lime use efficiency for different targeted areas for liming.

	Amount of lime (t)	Area to lime (ha)	Yield increase (t)	Av paddock yield t/ha	Lime use efficiency (kg grain/ t lime)
All paddock	480	120	58	2.04	121
Sandy soil	408	102	58	2.04	143
Average and below average yielding sandy soils	384	96	58	2.04	152
Just deep sand and acid sandy gravel	336	84	55	2.02	164
Just acid sandy gravel	168	42	34	1.84	204
None	0	0	0	1.56	0

Conclusions

This methodology allows farmers to identify areas of a paddock or farm which may be most responsive to amelioration. A large proportion of a paddock may be non-responsive to lime or liming the subsoil. This is typical of several paddocks that we have studied in the wheatbelt. In the example shown in Table 2, liming the whole (480ha) paddock gave the same yield increase (58t) as liming only the 384 ha of average and below average yielding sandy soils. Liming only 336 ha of responsive sands (liming 50 ha less) only decreased the response by 3 t to 55 t. Targeted liming is likely to improve profits. The area to be targeted can be identified by using a range of spatial data including gamma and EMI maps, grower mud map and knowledge of the farm, and google map coupled with severity identification.

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